

## CLAIMS

What is claimed is:

1. An electrolyte for a lithium-sulfur battery having a positive and a negative electrode, comprising:
  - a first component solvent with a sulfur solubility greater than or equal to 20 mM;
  - a second component solvent with a sulfur solubility less than 20 mM;
  - a third component solvent with a high dielectric constant and a high viscosity; and
  - an electrolyte salt.
2. The electrolyte for the lithium-sulfur battery of claim 1, wherein said first component solvent is roughly between 5% and 30% by volume of the electrolyte,
  - said second component solvent is roughly between 20% and 70% by volume of the electrolyte, and
  - said third component solvent is roughly between 20% and 70% by volume of the electrolyte.
3. The electrolyte for the lithium-sulfur battery of claim 1, wherein a difference in sulfur solubility between said first component solvent and said second component solvent is more than 20mM.
4. The electrolyte for the lithium-sulfur battery of claim 1, wherein said second component solvent and said third component solvent are mixed in a ratio of 1:1.
5. The electrolyte for the lithium-sulfur battery of claim 1, wherein said first component solvent is at least one selected from a group consisting of benzene, fluorobenzene, toluene, trifluorotoluene, xylene, cyclohexane, tetrahydrofurane, and 2-methyl tetrahydrofurane.
6. The electrolyte for the lithium-sulfur battery of claim 1, wherein said second component solvent is at least one selected from a group consisting of cyclohexanone, ethanol, isopropanol, dimethyl carbonate, ethylmethyl carbonate, diethyl carbonate, methylpropyl carbonate, methyl propionate, ethyl propionate, methyl acetate, ethyl acetate, propyl acetate, dimethoxy ethane, 1,3-dioxolane, diglyme (2-methoxyethyl ether), and tetraglyme.

7. The electrolyte for the lithium-sulfur battery of claim 1, wherein said third component solvent is at least one selected from a group consisting of ethylene carbonate, propylene carbonate,  $\gamma$ -butyrolactone, and sulforane.

8. The electrolyte for the lithium-sulfur battery of claim 1, further comprising an additive gas which forms a solid electrolyte interface (SEI) at a surface of the negative electrode during charging.

9. The electrolyte for the lithium-sulfur battery of claim 8, wherein said additive gas is at least one selected from a group consisting of  $\text{CO}_2$ ,  $\text{SO}_2$  and  $\text{N}_2\text{O}$ .

10. The electrolyte for the lithium-sulfur battery of claim 8, wherein said additive gas is roughly between 0.2% and 10% by weight of the electrolyte.

11. The electrolyte for the lithium-sulfur battery of claim 1, wherein said electrolyte salt is at least one selected from a group consisting of lithium hexafluorophosphate ( $\text{LiPF}_6$ ), lithium tetrafluoroborate ( $\text{LiBF}_4$ ), lithium hexafluoroarsenate ( $\text{LiAsF}_6$ ), lithium perchlorate ( $\text{LiClO}_4$ ), lithium trifluoromethane sulfonylimide ( $\text{LiN}(\text{CF}_3\text{SO}_2)_2$ ), and lithium trifluorosulfonate ( $\text{CF}_3\text{SO}_3\text{Li}$ ).

12. The electrolyte for the lithium-sulfur battery of claim 11, wherein a concentration of said electrolyte salt is roughly between 0.5 M and 2.0 M.

13. A lithium-sulfur battery comprising:

a negative electrode comprising a negative active material selected from a group consisting of lithium metal, lithium-containing alloy, a combination electrode of lithium/inactive sulfur, a compound that can reversibly intercalate a lithium ion, and a compound that can reversibly redoxidate with the lithium ion at a surface;

an electrolyte comprising a first component solvent with a sulfur solubility greater than or equal to 20 mM, a second component solvent with a sulfur solubility less than 20 mM, a third component solvent with a high dielectric constant and a high viscosity, and an electrolyte salt; and

a positive electrode comprising a positive active material comprising at least one sulfur-based material selected from a group consisting of sulfur element,  $\text{Li}_2\text{S}_n$  ( $n \geq 1$ ), organic sulfur compound and carbon-sulfur polymer ( $(\text{C}_2\text{S}_x)_n$  where  $x = 2.5$  to  $50$  and  $n \geq 2$ ), and electrically conductive material.

14. An electrolyte for use in a lithium-sulfur battery, comprising:

a mixture of solvents having different sulfur solubilities to dissolve sulfur and sulfur compounds, the sulfur compounds having a higher polarity than a polarity of the sulfur; a high dielectric solvent having a high dielectric constant; and an electrolyte salt.

15. The electrolyte of claim 14, wherein said mixture comprises first and second solvents, wherein a relative amount of the first and second solvents is determined in accordance with a relative amount of the sulfur and the sulfur compounds.

16. The electrolyte of claim 15, wherein a relative amount of the second solvent and said high dielectric solvent is determined in accordance with the dielectric constants and viscosities of the second solvent and said high dielectric solvent.

17. The electrolyte of claim 14, wherein said mixture comprises a first solvent with a sulfur solubility greater than or equal to  $20$  mM and a second solvent with a sulfur solubility less than  $20$  mM.

18. The electrolyte of claim 17, wherein:

the first solvent is roughly between  $5\%$  and  $30\%$  by volume of the electrolyte, the second solvent is roughly between  $20\%$  and  $70\%$  by volume of the electrolyte, and said high dielectric solvent is roughly between  $20\%$  and  $70\%$  by volume of the electrolyte.

19. The electrolyte of claim 17, wherein the difference in the sulfur solubility between the first solvent and the second solvent is more than  $20$  mM.

20. The electrolyte of claim 14, wherein one of the solvents of said mixture is at least one selected from a group consisting of benzene, fluorobenzene, toluene, trifluorotoluene, xylene, cyclohexane, tetrahydrofurane, and 2-methyl tetrahydrofurane.

21. The electrolyte of claim 14, wherein one of the solvents of said mixture is at least one selected from a group consisting of cyclohexanone, ethanol, isopropanol, dimethyl carbonate, ethylmethyl carbonate, diethyl carbonate, methylpropyl carbonate, methyl propionate, ethyl propionate, methyl acetate, ethyl acetate, propyl acetate, dimethoxy ethane, 1,3-dioxolane, diglyme (2-methoxyethyl ether), and tetraglyme.

22. The electrolyte of claim 14, wherein said high dielectric solvent is at least one selected from a group consisting of ethylene carbonate, propylene carbonate,  $\gamma$ -butyrolactone, and sulforane.

23. A lithium-sulfur battery, comprising:

a negative electrode comprising a negative active material;  
an electrolyte comprising a mixture of solvents having different sulfur solubilities to dissolve sulfur and sulfur compounds, the sulfur compounds having a higher polarity than a polarity of the sulfur, a high dielectric solvent having a high dielectric constant, and an electrolyte salt; and

a positive electrode comprising a positive active material.

24. The battery of claim 23, wherein said electrolyte further comprises an additive to prevent the formation of dendrite on a surface of said negative electrode.

25. The battery of claim 23, wherein said electrolyte further comprises an additive to form a solid electrolyte interface on a lithium metal surface of said negative electrode.

26. The battery of claim 23, wherein the mixture comprises first and second solvents, where a relative amount of the first and second solvents is determined in accordance with a relative amount of the sulfur and the sulfur compounds.

27. The battery of claim 26, wherein a relative amount of the second solvent and the high dielectric solvent is determined in accordance with the dielectric constants and viscosities of the second solvent and the high dielectric solvent.

28. The battery of claim 23, wherein the mixture comprises a first solvent with a sulfur solubility greater than or equal to 20 mM and a second solvent with a sulfur solubility less than 20 mM.

29. The battery of claim 28, wherein:

the first solvent is roughly between 5% and 30% by volume of said electrolyte,

the second solvent is roughly between 20% and 70% by volume of said electrolyte, and

the high dielectric solvent is roughly between 20% and 70% by volume of said electrolyte.

30. The battery of claim 28, wherein the difference in the sulfur solubility between the first solvent and the second solvent is more than 20mM.

31. The battery of claim 23, wherein one of the solvents of the mixture is at least one selected from a group consisting of benzene, fluorobenzene, toluene, trifluorotoluene, xylene, cyclohexane, tetrahydrofuran, and 2-methyl tetrahydrofuran.

32. The battery of claim 23, wherein one of the solvents of the mixture is at least one selected from a group consisting of cyclohexanone, ethanol, isopropanol, dimethyl carbonate, ethylmethyl carbonate, diethyl carbonate, methylpropyl carbonate, methyl propionate, ethyl propionate, methyl acetate, ethyl acetate, propyl acetate, dimethoxy ethane, 1,3-dioxolane, diglyme (2-methoxyethyl ether), and tetraglyme.

33. The battery of claim 23, wherein the high dielectric solvent is at least one selected from a group consisting of ethylene carbonate, propylene carbonate,  $\gamma$ -butyrolactone, and sulforane.